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CHAPTER 6.6

REINFORCED-PLASTIC/ COMPOSITE (RP/C) PARTS

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PROCESSES

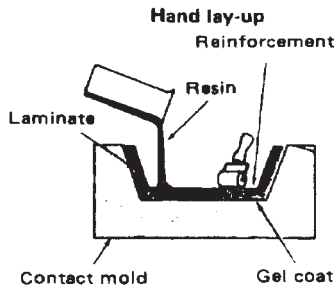
The molding of reinforced plastics/composites (RP/C) basically involves embedding a strong reinforcing material (fiberglass, asbestos, carbon fiber, etc.) into a liquid-that-becomes-solid polymeric matrix (polyester, epoxy, polypropylene, etc.). In the case of thermosetting plastics, the change from liquid to solid is effected by catalysts and heat. In the case of thermoplastic materials, it simply involves a cooling of the melted plastic to a temperature below its softening point. The specific shape and size of the part and the production quantity dictate which molding method will be used. A series of schematic illustrations of the various RP/C molding methods is presented in Fig. 6.6.1.

TYPICAL CHARACTERISTICS AND APPLICATIONS

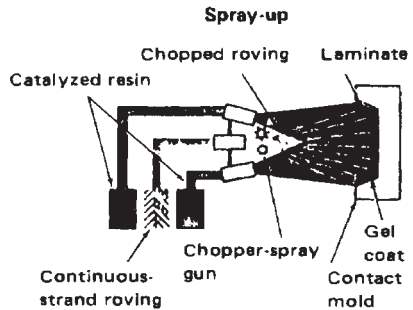
Favorable characteristics of RP/C construction are a high degree of design freedom, ability to use fewer parts by combining what otherwise would be separate parts into one component, a high strength-to-weight ratio, excellent corrosion resistance, excellent appearance with a smooth surface and molded-in color, electrical- and thermal-insulation properties, and easy repairability. The physical strengths of the material depend on the glass content and method of molding and can be designed to a desired level within a wide range of possibilities. Processing advantages include low tooling costs and short tooling lead times and availability of a wide choice of molding methods.

In addition, adaptability is gained by using RP/C components together with other materials by incorporating metal inserts, by joining several parts with mechanical fasteners or adhesives, or by encapsulating as with sandwich construction.

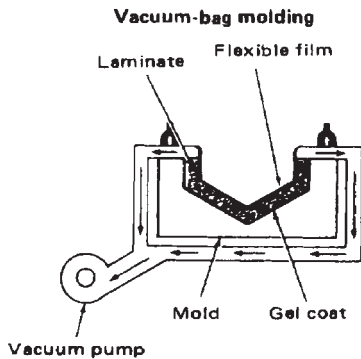
Limitations of the material include a maximum temperature of 120 or 150°C (250



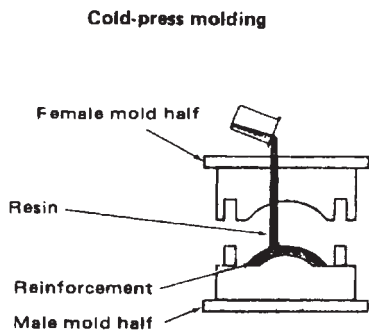
Products include boats, medium to large building components, and housings.



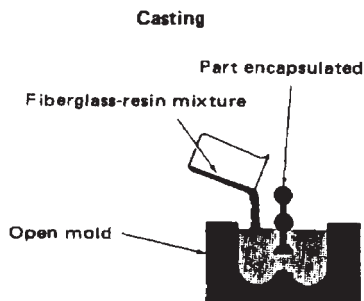
Same uses as hand lay-up plus tub and shower units.



Chiefly radomes. Provides parts of somewhat higher quality



Housings and other components for which two finished surfaces are required.



Includes potting and encapsulation for electrical components and also marbled sink, vanity, and bathroom-wall panels.

(a)

FIGURE 6.6.1a Room-temperature-cure RP/C molding methods. (Sketches reproduced by permission of Owens-Corning Fiberglas Corporation.)

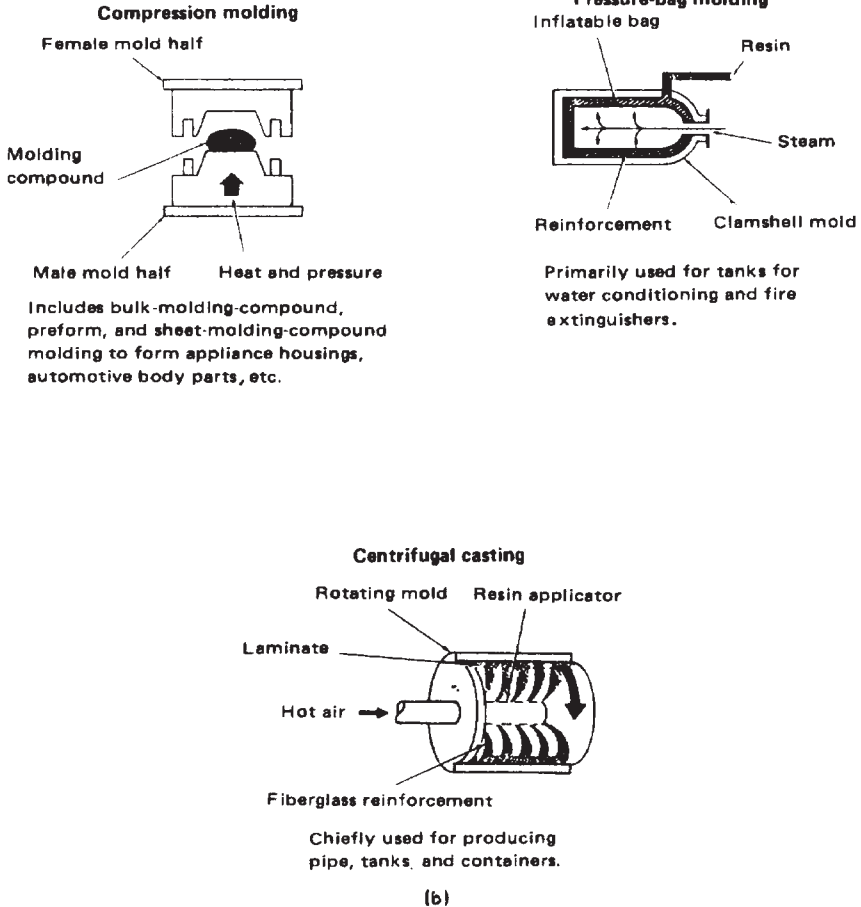


FIGURE 6.6.1b Thermoset processes requiring pressure. (Sketches reproduced by permission of Owens-Corning Fiberglas Corporation.)

or 300°F) for continuous service, creep or cold flow that precludes use for most sustained heavy-load-bearing applications, weaknesses around drilled or punched holes owing to severing of the reinforcing fibers, and poor resistance to severe abrasion or repeated heavy impact when compared with metals. However, many of these limitations may be overcome with proper design.

RP/C parts range in size from small, rapidly produced mechanical components such as gears or distributor caps, through continuously produced rods, girder stock, or architectural paneling, to extremely large tanks as much as 12.8 m (42 ft) in diameter by 12.2 m (40 ft) high.

Figure 6.6.2a through 6.6.2f illustrate representative RP/C parts or products fabricated by various molding methods.

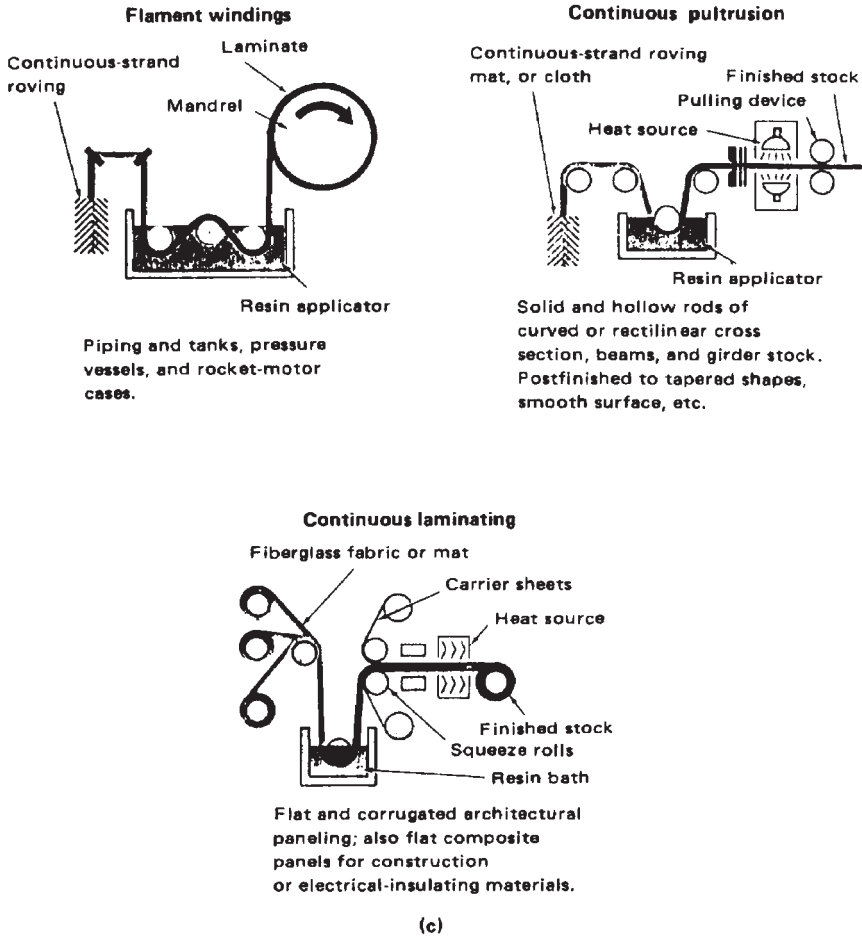


FIGURE 6.6.1c Continuous throughput processes. (Sketches reproduced by permission of Owens-Corning Fiberglas Corporation.)

Mode and Percentage of Reinforcement

Reinforcement may be random or directionally oriented and may vary in length from short milled fibers (for casting) to chopped strands from 3 mm ($\frac{1}{8}$ in) to 50 mm (2 in) or longer. It also may be sold in prepared mats or woven fabrics (for hand lay-up, etc.) or as continuous lengths (for filament winding). Mechanical strength is generally favored by increased amounts of the reinforcing agent, while good electrical properties require a dispersion of the high-dielectric-glass filaments throughout the molded part. Reinforcement quantities vary from a low of 1 or 2 percent (casting and some rotational-molding applications), through the nominal 20 to 40 percent for the majority of uses (hand lay-up, compression and injection molding, and centrifugal casting), to a high of 65 to 85 percent (for specialty compression molding, pultrusion, and fila-

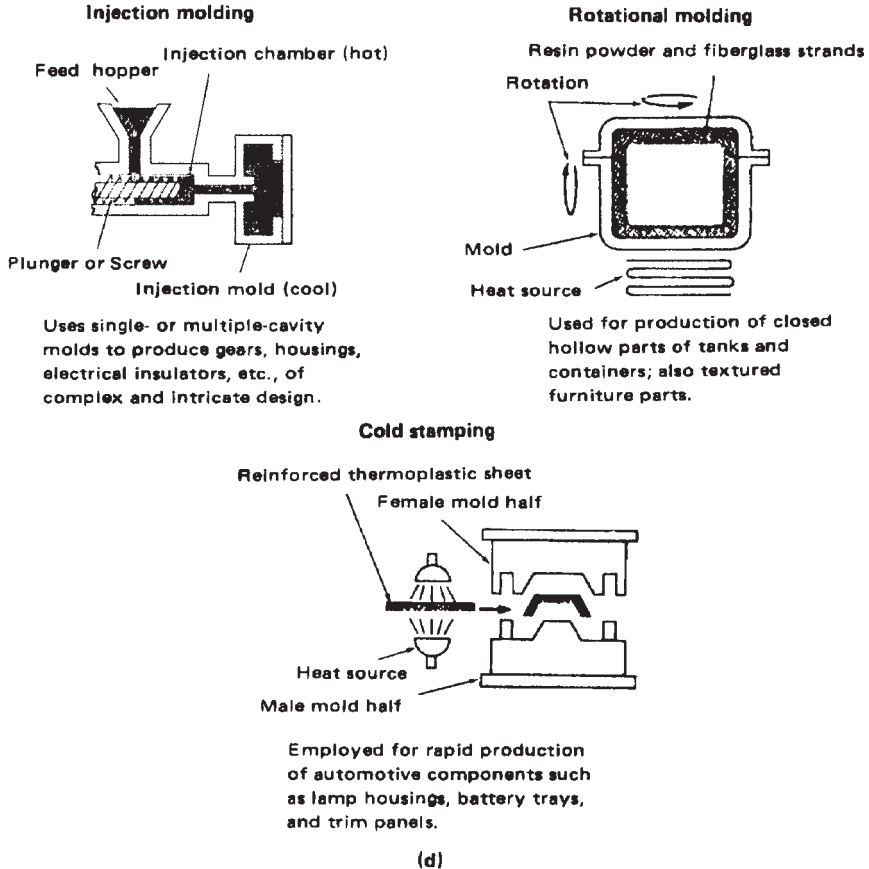


FIGURE 6.6.1d Processes for molding reinforced-thermoplastic resins. (Sketches reproduced by permission of Owens-Corning Fiberglas Corporation.)

ment winding). Naturally, highest physical strengths are provided in the direction of major glass-fiber orientation.

Surfaces

Gel coats are surface layers of material not containing reinforcing fibers. Normally 0.25 to 0.30 mm (0.010 to 0.012 in) thick, they are formed by applying and curing a highly filled resin layer. They may be designed for a range of characteristics such as improved appearance, chemical resistance, weather and craze resistance, abrasion resistance, etc.

Vacuum-formed acrylic or other thermoplastic elements form the outer skin



FIGURE 6.6.2a Sleighs made by the hand-lay-up process. (Courtesy Bay View Plastic, Inc.)



FIGURE 6.6.2b Tub and shower units made by the spray-up process. (Courtesy Universal-Rundle Corp.)

(replacing gel coats) on many RP/C items such as sinks and vanities, with good-adhering fiber-glass resin applied as backing for rigidizing. Mold and operating costs are greatly reduced, and some of the defects associated with gel coats are eliminated.

Incorporation of low-shrink additives in bulk molding compounds (BMC) and sheet molding compounds (SMC) has greatly enhanced acceptance and utilization of RP/C parts by avoiding the fiber pattern that formerly resulted when the fibers were revealed after molding because of resin contracting around them.



FIGURE 6.6.2c Acrylic-faced hand-bowl unit made by vacuum forming and spray-up (rigidizing). (Courtesy J. S. Johns Co.)



FIGURE 6.6.2d Radomes made by the vacuum-bag molding process. (Courtesy Century Plastics, Inc.)

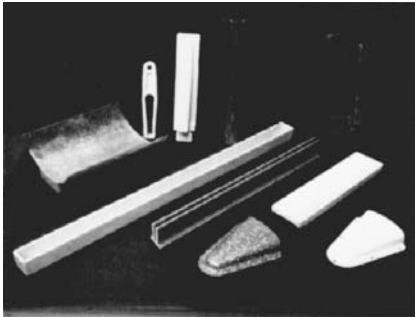


FIGURE 6.6.2e Products including motor base, channels, etc., made by the cold-molding process. (Courtesy Bay View Plastic, Inc.)

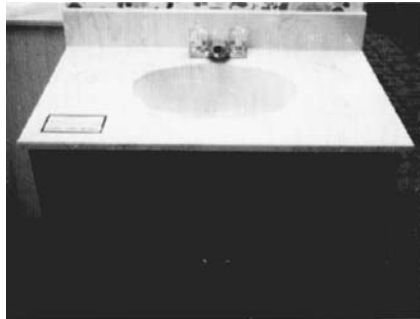


FIGURE 6.6.2f Sink made by the casting process. (Courtesy Creative Marble.)

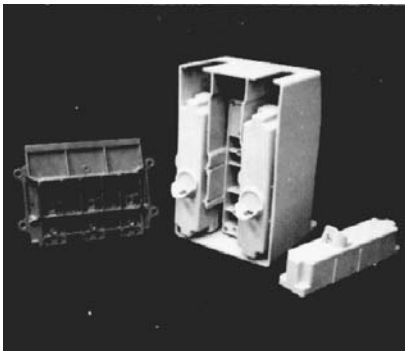


FIGURE 6.6.2g Electrical components made by the BMC molding process. Note molded-in inserts.

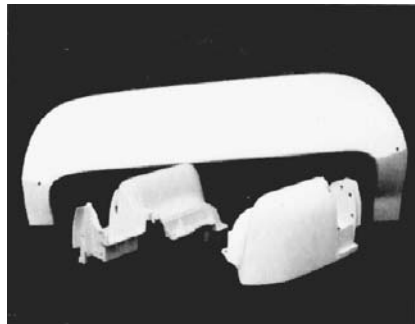


FIGURE 6.6.2h Automotive fender skirt and fender extensions made by using SMC molded-in heated matched-metal dies.



FIGURE 6.6.2i 5000-gal tank made by the filament-winding process. (Courtesy Justin Enterprises and Johns-Manville Corp.)



FIGURE 6.6.2j Typical cross-sectional shapes which can be produced by pultrusion. (Courtesy Morrison Molded Fiber Glass Co.)

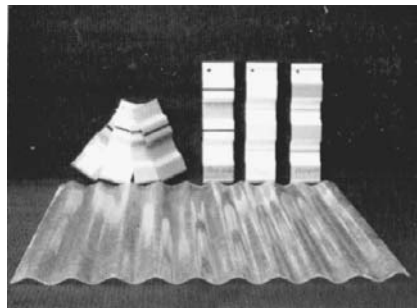


FIGURE 6.6.2k Corrugated architectural paneling made by the continuous-laminating process. (Courtesy The Society of the Plastics Industry, Inc.)

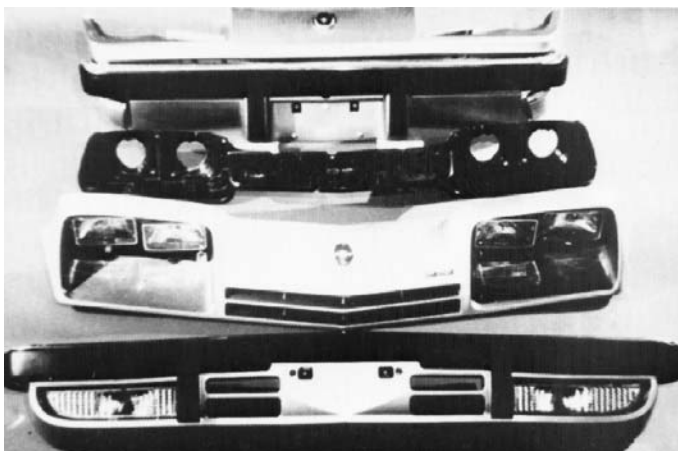


FIGURE 6.6.21 Automotive front-end lamp and bumper assembly (third part to rear; black) was molded by using the cold-stamping process. The other parts were molded by other processes. (Courtesy GRTL Co.)

Translucency

The resins used in fabricating RP/C are clear, but because they are reinforced and/or filled, they are prevented from being transparent. Translucency is readily accomplished by the use of either small amounts of filler or none and thinner sections. Flat or corrugated architectural paneling is the primary RP/C product having this property, and the panels are colored or tinted for pleasing effects. Applications include room dividers, patio covers, garage doors, insulating walls (double-glazed), decorative sandwich laminates with embedments, building lights, solar-heat collectors, greenhouse and poultry-farm panels, etc. The translucency of RP/C components is also useful in large hand-lay-up and filament-wound tanks or piping where the level of the contained liquid may be readily observed.

ECONOMIC PRODUCTION QUANTITIES

The optimal production quantity for RP/C parts (from a cost standpoint) varies tremendously depending on the process used. Hand lay-up methods are most suitable for very limited quantities, while injection molding requires mass-production levels to amortize tooling and equipment investments.

Table 6.6.1 summarizes normal economic production quantities for the common RP/C processes. Relative tooling and equipment costs and output rates are shown.

In general, larger parts will require longer production times than small parts, and increased production rates will result from mechanized and automated processes.

Table 6.6.2 shows normal mold life in terms of the number of parts producible from a single-cavity mold peculiar to each RP/C process. It also presents relative cost data for molds.

TABLE 6.6.1 Economic Production Quantities for Various RP/C Molding Methods*

Molding method	Relative investment required		Relative production rate	Economic production quantity
	Equipment	Tooling		
Hand lay-up	VL	L	L	VL
Spray-up	L	L	L	L
Casting	M	L	L	L
Cold-press molding	M	M	L	L
Vacuum-bag molding	M	L	VL	VL
Compression-molded BMC	H	VH	H	H
SMC and preform	H	VH	H	H
Pressure-bag molding	H	H	L	L
Centrifugal casting	H	H	M	M
Filament winding	H	H	L	L
Pultrusion	H	H	H	H
Continuous lamination	H	H	H	H
Cold stamping	H	H	H	H
Rotational molding	H	H	L	M
Injection molding	VH	VH	VH	VH

*VL = very low; L-low; M-medium; H-high; VH-very high.

TABLE 6.6.2 Mold Life and Mold Cost for Various RP/C Molding Processes

RP/C process	Approximate number of parts from mold (mold life)	Relative mold cost	Type of mold
Hand lay-up	800–1000	Lowest	RP/C
Spray-up	100–200	Lowest	RP/C
Vacuum-bag molding	100–200	Low	RP/C
Cold-press molding	150–200	Medium	RP/C
Casting, electrical	3500	High	Metal
Casting, marble	300–500+	Lowest	RP/C
Compression molding: BMC	120,000	High	Metal
Matched-die molding: SMC	300,000–400,000	Highest	Metal
Pressure-bag molding	Over 1,000,000	Medium	Metal
Centrifugal casting	Over 1,000,000	Low	Metal
Filament winding	Almost unlimited	Lowest	Metal
Pultrusion	Almost unlimited	Minimal	Metal
Continuous laminating	Almost unlimited	Minimal	Metal
Injection molding:reinforced thermoplastic (RTP)	300,000–1,000,000	Highest	Metal
Rotational molding	100,000	Low	Metal
Cold stamping	1,000,000–3,000,000	Highest	Metal

GENERAL DESIGN CONSIDERATIONS

The first quest of a designer planning an RP/C part is to determine, from its size, shape, quantity to be produced, and strength requirements, which method should be used in fabrication. This is important because design principles vary considerably with the molding method. For example, there are limitations to the depth of draw obtainable with sheet molding compounds that do not apply to preforms. The component should be designed with a specific process in mind.

A second principle is to show the preliminary design to prospective molders. It is always sound advice to consult the prospective fabricator of any part, but this is especially so in the case of RP/C parts, for which a considerable variety of manufacturing processes is available.

The next major consideration, once the design shape has been finalized, is the type of resin and reinforcing materials to specify. Resins may be rigid or resilient or may be made fire-retardant, resistant to water or chemicals, light-stable for nondiscoloration, or have other special properties.

Shrinkage occurs during the cure of resins for all processes. Designers should allow for the dimensional changes and distortion that can result from shrinkage. Shrinkage may be reduced or controlled by additives in molding SMC and BMC in matched-metal dies. Shrinkage usually assists in removing parts from molds. (The exception occurs when the part shrinks onto the mold, as in filament winding.)

SUITABLE MATERIALS

Thermosetting Resins

Polyester Resins. Polyesters are lowest in cost and possess the most facile and trouble-free processibility of any thermosetting resins. They are the workhorses of the industry and are used for most general-purpose applications in room-temperature, intermediate-, or high-temperature cures. They also may be modified by composition or additives to provide improved chemical durability, electrical properties, light stability, weather resistance, high-heat resistance, or other properties. The modifications result in increased materials cost with minimum change in processing qualities. Vinyl ester resins are included in this polyester-resin category.

Epoxy Resins. These resins are medium to high in price and qualify as easy to somewhat difficult in processibility. They respond to room-temperature, intermediate-, and high-temperature cures by selection of the proper catalyst system. Epoxy resins are tougher and have lower shrinkage than polyesters (excluding additives). Prime end uses are in electrical applications and in filament winding for dimensional stability. Chemical resistance is no greater than for polyester resins and is specific. Adhesion is excellent.

Phenolic Resins. Phenolics are low in cost but difficult to process by usual RP/C standards, since most molding methods for their use call for high temperatures and pressures. A number of reinforcements and fillers are used with phenolics (see Chap. 6.1).

Alkyd Resins. Medium to high in price and difficult to process (again requiring high pressures), alkyd resins are usually sold as formulated molding compounds for use in applications requiring high electrical performance.

Diallyl Phthalate Resins. These are medium- to high-priced and difficult to process, mostly requiring high temperatures and pressures. They are purveyed mostly in molding-compound or preimpregnated-mat form and yield such molded properties as high hardness, clarity, and low shrinkage.

Furfural Alcohol Resins. Also termed *furan* resins, these are low-priced but are processed with difficulty owing to malodor and the need for a hazardous catalyst system based on H_2SO_4 . Furfural alcohol resins have excellent chemical durability, even surpassing polyesters, so their processing problems are sometimes justified. Whereas they were formerly moldable only in press operations, in recent years wet or hand-lay-up types have been made available by buffering the catalyst systems or otherwise making them easier to use. Fiberglass is the main reinforcement, and fillers are used according to end requirements.

Silicone Resins. These resins are extremely high in price and possess difficult processing characteristics. Their use in RP/C is limited. Glass is the major reinforcement, and a number of fillers are used. However, the resulting molded products are comparatively low in strength. Electrical and high-temperature applications are the major end uses.

Thermoplastic Resins

At least 15 resin types are processible as reinforced thermoplastics. Their prices range from medium to high. Processibility for all is relatively easy and rapid and is carried out primarily in injection-molding equipment. Fiberglass reinforcement up to 40 percent or more by weight upgrades these materials into the engineering-plastics classification. Characteristic resin types include all molecular configurations of the nylons, acetal, polyethylenes (also the principal resins used in rotational molding and cold stamping), polypropylene, ionomer, polybutylene terephthalate (PBT), polycarbonate, polysulfone, polyphenylene oxide, polystyrene and the related styrenics (SAN and ABS), fluoroplastic polytetrafluoroethylene (PTFE; highest-priced), rigid PVC, polyurethane, and polyphenylene sulfide. The last two are the next highest priced.

Reinforcements

Fiberglass. Fiberglass, the most widely used general-purpose reinforcement, is low to medium in cost. It is also the most readily processible reinforcement, with a form for each specific type of molding of RP/C: yarns, woven tapes and fabrics, veil and random-fiber-oriented mats, rovings and woven roving, chopped strands, and milled fibers. Related glass forms are solid and hollow beads and glass flake. Reinforcement levels average 20 to 35 percent and range from 2 to 5 percent (premix and rotational molding) to 75 to 85 percent (filament winding). All fiberglass-reinforcing products supplied contain an organic sizing material (0.5 to 2.5 percent by weight) designed to promote compatibility with the resin, method of molding, and end use. This sizing should be investigated and specified in the product design.

Asbestos. This natural mineral reinforcement is low in cost and readily processible. Forms available are bulk fibers in many lengths, woven tapes and fabrics, and both

parallel-fiber and random-oriented mats. Asbestos provides good uniform and hard surfaces in molding compounds such as premix for electrical applications. Because of health hazards to workers handling it, asbestos is now used much less frequently than previously.

Natural Organic Fibers: Sisal, Jute, and Cotton. Sisal prices have risen to levels above those for glass fiber in recent years, taking away one of the most desirable factors. Processibility is excellent for limited applications (BMC) because the material is a monofilament and is highly resistant to degradation in processing. Sisal and jute are available in chopped fiber lengths and also in unidirectional mats. The mats may be cross-plyed for greater load-carrying capacity in hand-lay-up structures. These natural fibers possess high water absorption, which limits their use as reinforcements.

Synthetic Organic Fibers: Nylon, Polyester, Acrylonitrile, and Polyvinyl Alcohol. These fibers are medium in cost and excellent for processibility.

High-Performance Fibers: Carbon, Graphite, Metal, Boron, and Ceramic Fibers. These fibers are high-priced and medium to difficult to process, but all generate highly desirable improvements in RP/C. Carbon and graphite yield high strengths and a high modulus of elasticity plus lightness in weight. Applications are golf shafts and empennage structures for aircraft. SiO_2 , Al_2O_3 , other ceramic fibers, and boron also have been used.

Fillers

Clays and calcium carbonate are the fillers used in the largest volume; their level ranges from 15 to 80 percent of the weight of finished molded parts. Other fillers and their respective functions are short-fibered asbestos, which has good surface and electrical properties but imparts a characteristic greenish color; $\text{Mg}(\text{OH})_2$ and powdered or liquid thermoplastic polymers, which respectively provide the desirable thickening and low-shrink factors in SMC; finely divided silicas, which control viscosity and prevent rundown in hand-lay-up resins; and talcs, which provide easy sanding in body putty, lightness of weight, and good electrical properties. Other filler additives reduce flammability, improve abrasion resistance, and improve corrosion and weathering resistance. Even water is used in the emulsified form as a filler-extender in casting resins.

DETAILED DESIGN RECOMMENDATIONS

Design recommendations expressed in Chap. 6.1, "Thermosetting-Plastic Parts," are generally applicable to compression, transfer, and injection molding of thermoset RP/C and need not be repeated here. Similarly, almost all design recommendations in Chap. 6.2, "Injection-Molded Thermoplastic Parts," apply equally well to injection-molded thermoplastic parts using reinforcements and fillers and are not repeated here. Design recommendations included below are applicable primarily to RP/C processes not duplicated in these chapters.

TABLE 6.6.3 Wall-Thickness Ranges and Tolerances for RP/C Parts

Molding method	Thickness range		Maximum practicable buildup within individual part	Normal thickness tolerance, mm (in)
	Min., mm (in)	Max., mm (in)		
Hand lay-up	1.5 (0.060)	30 (1.2)	No limit; use cores	±0.5 (0.020)
Spray-up	1.5 (0.060)	13 (0.5)	No limit; use many cores	±0.5 (0.020)
Vacuum-bag molding	1.5 (0.060)	6.3 (0.25)	No limit; over three cores possible	±0.25 (0.010)
Cold-press molding	1.5 (0.060)	13 (0.5)	3–13 mm ($\frac{1}{8}$ – $\frac{1}{2}$ in)	±0.5 (0.020)
Casting, electrical	3 ($\frac{3}{8}$)	115 (4 $\frac{1}{2}$)	3–115 mm ($\frac{1}{8}$ –4 $\frac{1}{2}$ in)	±0.4 (0.015)
Casting, marble	10 ($\frac{3}{4}$)	25 (1)	10–13 mm; 19–25 mm ($\frac{3}{8}$ – $\frac{1}{2}$ in; $\frac{3}{4}$ –1 in)	±0.8 ($\frac{1}{2}$)
BMC molding	1.5 (0.060)	25 (1)	Min to max. possible	±0.13 (0.005)
Matched-die molding; SMC	1.5 (0.060)	25 (1)	Min. to max. possible	±0.13 (0.005)
Pressure-bag molding	3 ($\frac{3}{8}$)	6.3 ($\frac{1}{4}$)	2:1 variation possible	±0.25 (0.010)
Centrifugal casting	2.5 (0.100)	4 $\frac{1}{2}$ % of diameter	5% of diameter	±0.4mm for 150-mm diameter (0.015 in for 6-in diameter); ±0.8 mm for 750-mm diameter (0.030 in for 30-in diameter)
Filament winding	1.5 (0.060)	25 (1)	Pipe, none; tanks, 3:1 around ports	Pipe, ±5%; tanks, ±1.5 mm (0.060 in)
Pultrusion	1.5 (0.060)	40 (1.6)	None	1.5 mm, ±0.025 mm ($\frac{1}{16}$ in, ±0.001 in); 40 mm, ±0.5 mm (1 $\frac{1}{2}$ in, ±0.020 in)
Continuous laminating	0.5 (0.020)	6.3 ($\frac{1}{4}$)	None	±10% by weight
Injection molding	0.9 (0.035)	13 (0.5)	Min. to max. possible	±0.13 (0.005)
Rotational molding	1.3 (0.050)	13 (0.5)	2:1 variation possible	±5%
Cold stamping	1.5 (0.060)	6.3–13 (0.25–0.50)	3:1 possible as required	± 6.5% by weight; ±6.0% for flat parts

Wall Thickness

Thickness minima and maxima for each process are given in Table 6.6.3. Thickness may be varied within parts, but prolonged cure times, slower production rates, and the possibility of warpage result. If possible, thickness should be held uniform throughout a part.

For hand-lay-up and spray-up methods, extra thicknesses can be built up by first allowing the lay-up to cool from its exotherm, but extra material should be added before 24 h have elapsed. Thicker wall sections, if needed, should be cored or sand-wiched as shown in Fig. 6.6.7 to minimize weight increase and avoid distortion.

Mold Parting Line and External Edges

In all press-molding methods (BMC, SMC, preforming, cold pressing, cold stamping, etc.) a design that permits a straight mold parting line is preferred because it simplifies mold construction. Open hand lay-up and spray-up molding do not require a straight edge on the part because edge-finishing operations are carried out by hand and can easily follow steps and curves.

Draft

Draft is advisable on the sidewalls of all press-molded RP/C parts and on all interior and exterior surfaces, including all ribs and bosses. The minimum recommended draft angle is $\frac{1}{2}^\circ$. However, angles in the range of 1 to 3° and in some cases more are preferable. (See Fig. 6.6.3.) Interior surfaces usually require more draft than exterior surfaces because shrinkage of the part prevents release rather than aiding it. Low-shrinkage materials also may necessitate greater draft on exterior surfaces. Surface textures also increase the need for draft. For each 0.025 mm (0.001 in) of depth of surface texture, 1° additional draft should be allowed.

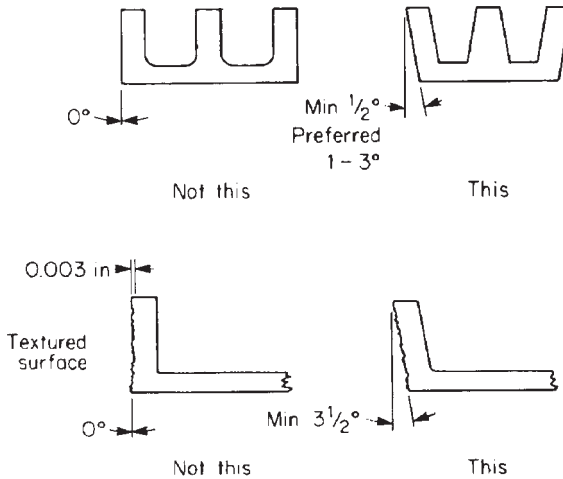


FIGURE 6.6.3 Recommendations for draft on sidewalls and other vertical members of press-molded RP/C parts. Textured surfaces require much more draft than smooth surfaces.

Open-Lay-Up (Hand-Lay-Up, Spray-Up, Vacuum-Bag) Moldings. Adequate draft is required if molds are rigidly braced. However, the flexible nature of the molds used for these processes allows zero draft or some reverse curvature to be molded in, as shown in Fig. 6.6.4.

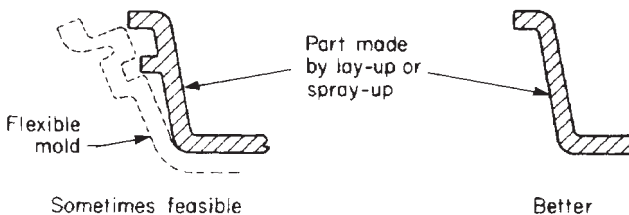


FIGURE 6.6.4 Flexible molds used for open lay-up molding allow zero draft, reverse curvature, or undercuts in the part while still permitting removal of the part from the mold.

Undercuts

Press Molding. Undercuts should be avoided. They require core pulls (sliding mold members) or extra mold sections. These increase mold costs and cause difficulty if resin flows into mold joints. BMC, SMC, and injection molding are the best methods if undercuts must be included. Internal undercuts are not feasible with any process. (See Fig. 6.1.6 in Chap. 6.1.)

Open-Lay-Up Molding. As stated, undercuts should be avoided in general but may be designed in if the mold can be flexed without damage for part removal (Fig. 6.6.4). Also, slides or pulls may be built into the molds for intricate tooling work, or a split mold may be used. These are somewhat less of a problem with open-lay-up molding than with press methods because high pressures are not involved, but they still should be avoided.

Corner Radii

Press Molding. The more generous the inside-corner radii allowed the better, with 1.5 mm ($\frac{1}{16}$ in) being the minimum for most methods except preform molding, for which 3 mm ($\frac{1}{8}$ in) is recommended. This will promote material flow and avoid resin-rich or resin-starved areas. Outside radii probably will be dictated by part thickness, but they should not be less than 1.5 mm ($\frac{1}{16}$ in).

Open-Lay-Up Molding. Again, part function probably will dictate the shape of corner radii, but they should not be less than 6 mm ($\frac{1}{4}$ in).

Edge Stiffening

A straight unsupported edge will have a tendency to warp or to be too flexible. Flanges, wall thickening, and reinforcements may all be employed to avoid this problem. Figure 6.6.5 illustrates various edge-stiffening designs that are feasible with press-molded RP/C parts.

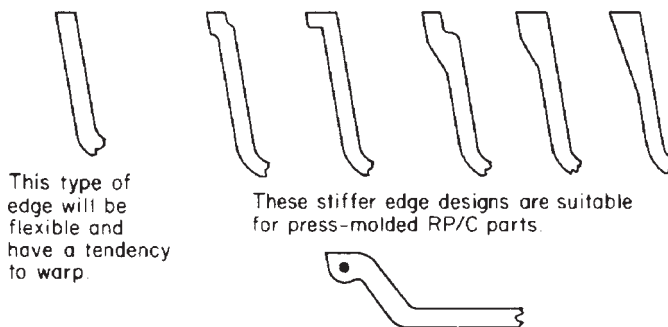


FIGURE 6.6.5 Feasible edge-stiffening designs for press-molded parts.

The large structures fabricated by using open lay-up methods require stronger bracing for the longer exposed edges even though part thicknesses are usually greater. Edges may be further braced by sandwich-type construction. Figure 6.6.6 illustrates several flange designs. Stiffness also may be imparted by impressing soft, porous wood forms of plywood into a basic laminate and laminating over them. Laminates may be substantially stiffened by incorporating layers of plywood, slab foam, balsa, etc. Figure 6.6.7 shows examples for ribs, but the same approach can be used for edge reinforcement.

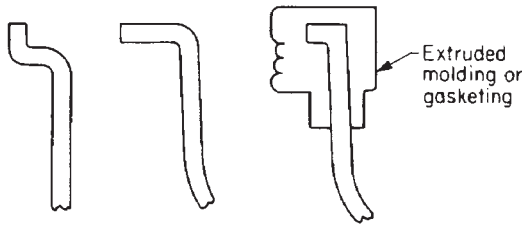


FIGURE 6.6.6 Edge-stiffening flanges for open-lay-up-molded RP/C parts.

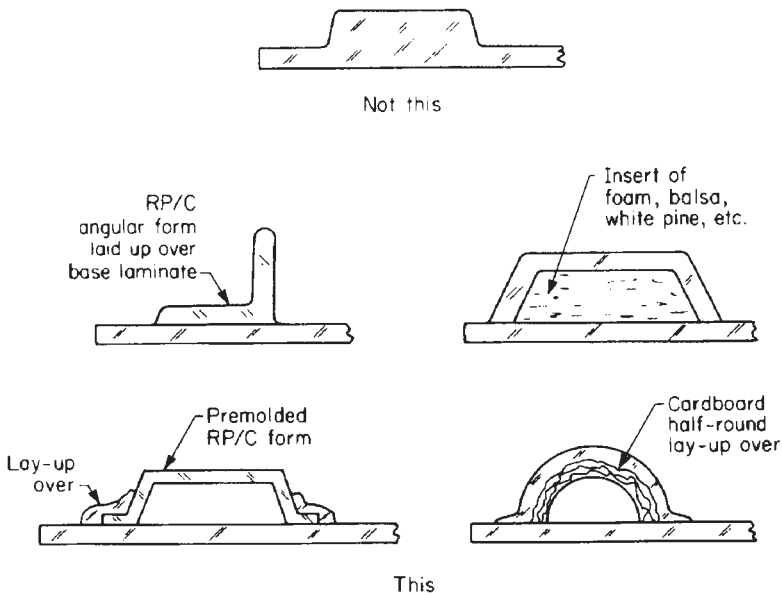


FIGURE 6.6.7 Design recommendations for ribs and other reinforcements of open-lay-up-molded parts.

Ribs

Press Molding. In press molding RP/C (SMC or BMC), a raised column or strip almost the same as nominal part thickness is preferred. Additional fillets or gussets aid

flow into the rib. Since sink marks may appear in the surface opposite a rib, it is best, if appearance is important, to minimize these marks or disguise them. They can be minimized by using minimum radii at the rib base and disguised by locating the rib behind styling lines or textured surfaces, as shown in Fig. 6.2.14.

Open-Lay-Up Molding. In the larger structures possible with hand lay-up or spray-up, ribs or stiffeners are preferably added by postmolding a fin or arched stiffener around a core rather than by a thickness buildup. The need for ribs can sometimes be eliminated by monocoque construction (double layers sandwiched around a wood, foam, or other lightweight core).

Bosses

Press Molding. Bosses follow approximately the same design rules as for press-molded ribs. Blind holes should be molded in to reduce mass. Reinforcing ribs are preferable to molding a heavy mass. The width of the shoulder should be no larger than the diameter of the hole. Locate bosses in corners if possible. (See Fig. 6.6.8.)

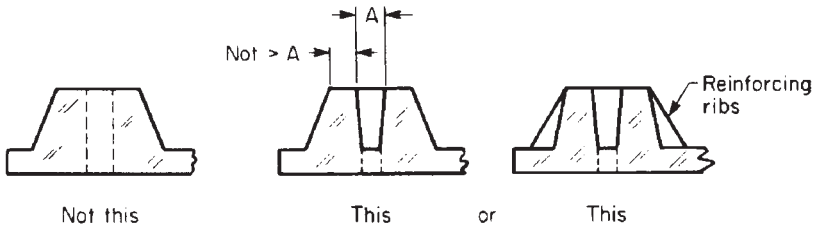


FIGURE 6.6.8 Boss design for press-molded RP/C parts.

Open-Lay-Up Molding. As in the case of ribbing, raised bosses for mounting should employ a buildup around a core material.

Holes and Openings

Holes present some difficulties in RP/C parts because they interfere with the distribution of the reinforcing fibers. Generally, the molding of holes is not recommended with preform, SMC, or cold-press molding. With these processes, holes may be drilled after demolding. Molded holes in BMC and injection-molded reinforced thermoplastics are feasible. However, holes with BMC are preferably molded as partial holes as shown in Fig. 6.6.9. In general, holes in RP/C press-molded parts should be two diameters from other holes and three diameters from part edges.

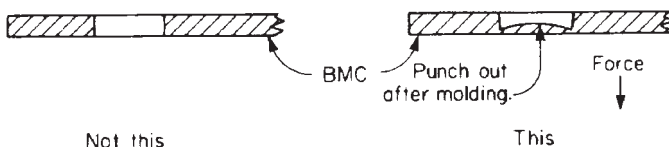


FIGURE 6.6.9 With BMC, partially molded holes for later punching out are recommended.

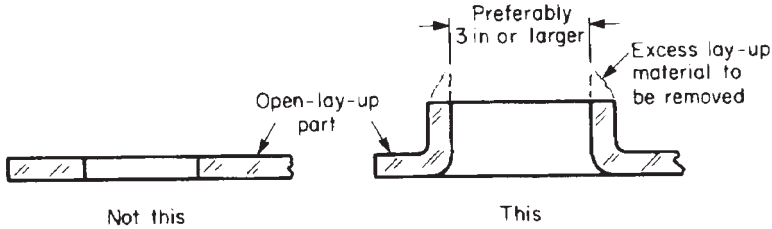


FIGURE 6.6.10 Preferred hole design in parts made by open lay-up methods.

Open-Lay-Up Molding. With open lay-up molding there is no satisfactory way to arrange the reinforcement fibers to produce a satisfactory hole in a flat wall. Instead, it is necessary to create a protrusion by draping the reinforcing mat, fabric, or roving around and over a plug in the mold. Excess material is cut off and trimmed after molding. The resulting part is stronger and more rigid than a flat section with a hole would be. (See Fig. 6.6.10.) Holes above 3-in diameter are feasible; the larger, the better.

Inserts and Threading

Press Molding. Inserts can be either molded in or set mechanically after molding, except with preform and cold-press molding, for which only after-molding assembly is recommended. A variety of interface surfaces, including diamond knurl, I-beam type, etc., may be employed for the molded-in inserts. Threads on inserts are preferable to threading molded RP/C parts.

Open-Lay-Up Molding. Inserts may be incorporated for a variety of applications such as bolting, joining, etc. Threading of open lay-up molded parts is not recommended. Insert flanges or bases should be as large as is feasible. Often inserts can be incorporated by applying additional material over the flange base of the insert, as shown in Fig. 6.6.11.

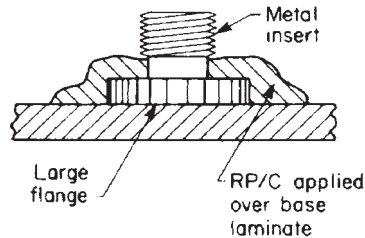


FIGURE 6.6.11 Wide-flanged metal inserts in RP/C parts can be fastened by applying material over the flange.

Surface Finish

Press Molding. The surface finish of the part is directly related to the mold finish. A variety of surface finishes can be specified for RP/C parts. The designer should bear in mind, however, that the smoother finishes normally are more costly than those in which fiber prominence is evident. However, the nonsrink additives used in SMC and BMC compounding generally ensure that the intended finish results.

Open-Lay-Up Molding. Surface finishes for hand lay-up and spray-up products again are a function of mold finish. Gel coats duplicate mold finish. Vacuum-formed thermoplastic sheets with RP/C backing provide excellent surfaces.

Joining RP/C Parts

Parts consolidation and the consequent reduction of necessary parts assembly are one of the advantages of RP/C construction. However, when the joining of separate parts is necessary, it may be handily accomplished by any of several worthwhile methods. Parts can be bonded together or held with mechanical fasteners. Figure 6.6.12 illustrates a number of recommended joint designs.

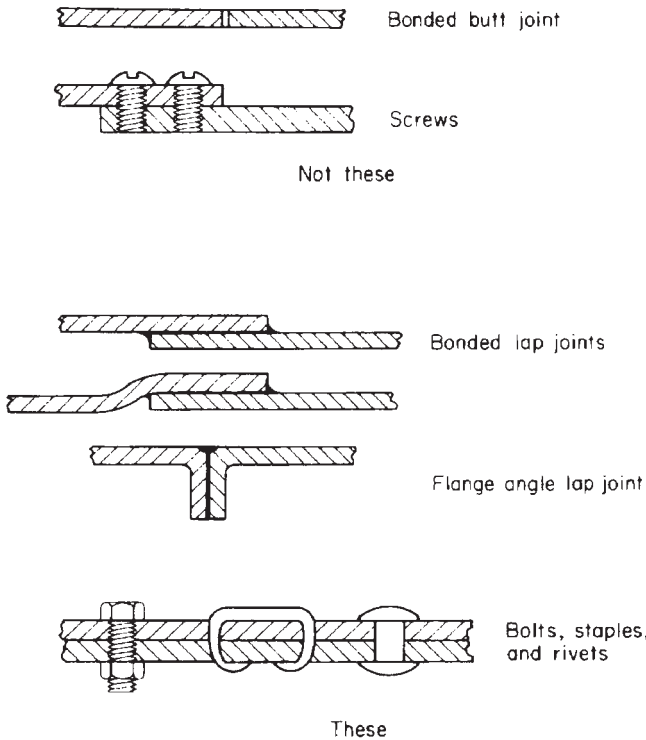


FIGURE 6.6.12 Recommendations for joint designs in assemblies of RP/C parts.

Flat Surfaces

Gently curved or rounded surfaces are preferred to flat surfaces. They are less apt to warp and flex. Normally only a small amount of curvature is necessary to improve a part's rigidity greatly, especially if flanges are also employed. If flatness is necessary in a particular surface, use ribbing or other stiffening members.

Lettering

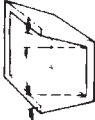
Molded-in lettering with raised or depressed characters is feasible with all RP/C processes except filament winding, pultrusion, and continuous laminating. Raised lettering on the part is normally preferable except when the mold itself is made of RP/C materials (as in the open-mold lay-up and spray-up methods). Labels can be molded into most RP/C parts, the exceptions being pultrusions and injection moldings.

Table 6.6.4 summarizes design recommendations for RP/C parts.

TOLERANCE RECOMMENDATIONS

Allowable wall-thickness variations for the products from all RP/C molding methods are shown in Table 6.6.3. Recommended tolerances for other dimensions of parts made with various RP/C processes are included in Table 6.6.5.

TABLE 6.6.4 Design Recommendations for Reinforced-Plastic/Composite Parts

		Compression molding				Injection molding (thermoplastics)	Cold-press molding	Spray-up and hand lay-up
		Sheet-molding compound	Bulk-molding compound	Preform molding				
Minimum inside radius		1/16 in	1/16 in	1/8 in	1/16 in	1/16 in	1/4 in	1/4 in
Molded-in holes		Yes*	Yes*	Yes*	Yes*	Yes*	No	Large
Undercuts		Yes†	Yes*	No	Yes†	Yes†	No	Yes†
Minimum recommended draft		1/4- to 6-in depth: 1 to 3° 6-in depth and over: 3° or as required					2° 3°	0°
Minimum practical thickness		0.050 in	0.060 in	0.030 in	0.035 in	0.035 in	0.080 in	0.060 in
Maximum practical thickness		1 in	1 in	0.250 in	0.500 in	0.500 in	0.500 in	No limit

		As required	2:1 max.	As required	2:1 max.	As required	2:1 max.	As required	2:1 max.	As required
Maximum thickness build-up, heavy buildup, and increased cycle		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	As required
Corrugated sections		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Metal inserts		Yes	Not recommended	Yes	Not recommended	Yes	Not recommended	Yes	Not recommended	Yes
Bosses		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ribs		As required	Not recommended	Yes	Not recommended	Yes	Not recommended	Yes	Not recommended	Yes
Molded-in labels		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Raised numbers		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Finished surfaces (reproduces mold surface)		Two	Two	Two	Two	Two	Two	Two	Two	One

*Parallel to ram action.

†With slides in tooling or split mold.

Source: Courtesy Owens-Corning Fiberglas Corp.

TABLE 6.6.5 Recommended Dimensional Tolerances for RP/C Parts

Dimension, mm (in)	Class A (fine tolerance), mm (in)*	Class B (normal tolerance), mm (in)†	Class C (coarse tolerance), mm (in)‡
0–25 (0–1)	$\pm 0.12 (\pm 0.005)$	$\pm 0.25 (\pm 0.010)$	$\pm 0.4 (\pm 0.016)$
25–100 (1–4)	$\pm 0.2 (\pm 0.008)$	$\pm 0.4 (\pm 0.016)$	$\pm 0.5 (\pm 0.020)$
100–200 (4–8)	$\pm 0.25 (\pm 0.010)$	$\pm 0.5 (\pm 0.020)$	$\pm 0.8 (\pm 0.030)$
200–400 (8–16)	$\pm 0.4 (\pm 0.016)$	$\pm 0.8 (\pm 0.030)$	$\pm 1.3 (\pm 0.050)$
400–800 (16–32)	$\pm 0.8 (\pm 0.030)$	$\pm 1.3 (\pm 0.050)$	$\pm 2.0 (\pm 0.80)$
800–1600 (32–64)	$\pm 1.3 (\pm 0.050)$	$\pm 2.5 (\pm 0.100)$	$\pm 3.8 (\pm 0.150)$
1.6–3.2 (64–128)	$\pm 2.5 (\pm 0.100)$	$\pm 5.0 (\pm 0.200)$	$\pm 7.0 (\pm 0.280)$

*Class A tolerances apply to parts compression-molded with precision matched-metal molds. BMC, SMC, and preform are included.

†Class B tolerances apply to parts press-molded with somewhat less precise metal molds. Cold press molding, casting, centrifugal casting, rotational molding, and cold stamping can apply to this classification when molding is done with a high degree of care. BMC, SMC, and preform compression molding can apply to this classification if extra care is not used.

‡Class C applies to hand-lay-up, spray-up, vacuum bag, and other methods using molds made of RP/C material. It applies to parts that would be covered by Class B when they are not molded with a high degree of care.